Botany, Chemistry, and Tropical Development

DANIEL R. HEADRICK
Roosevelt University

ECONOMISTS and economic historians have written a great deal about the causes of underdevelopment, but seldom in connection with advances in science. Historians of science, meanwhile, have regarded science either as a boon or as a threat to all humankind and have largely ignored its differential impacts on different parts of the world. In this paper I investigate the role of science and scientific technology in creating the current economic imbalance between the countries of the temperate zone and the poorer ones located in the tropics. In particular, I suggest that the economic consequences of two sciences, botany and chemistry, have contributed more to global disparities than scholars have heretofore acknowledged.

Imperialism and Tropical Trade before 1914

Relations between the North Atlantic countries and the tropics in the century before 1914 can be summed up by the term *imperialism*. Among the many causes of imperialism, both formal and informal, was the growing demand of Western consumers and industries for tropical products. The industrialization of the North Atlantic region caused a surge in demand for raw materials, such as cotton, indigo, rubber, palm oil, jute, sisal, and gutta-percha. At the same time, Europeans and North Americans became addicted to stimulants, such as tea, sugar, coffee, and cocoa. As more and more Europeans traveled to the tropics, they required increasing amounts of quinine to protect them against malaria.

If the tropics had met these growing demands with proportionate increases in supply, imperialist expansion might have been more tem-

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pered. But supplies did not increase spontaneously. Chinese farmers, hampered by a lack of land and inflexible farming methods, could not keep up with the growing demand for tea and silk. Nigerian palm oil merchants were content to reap the benefits of rising prices and had little interest in expanding production. Situations like these provided the incentives for imperialistic ventures, such as the Opium War of 1839–42 and the annexation of Lagos in 1851.

Yet coercion and conquest could not in and of themselves increase the production of tropical crops. To develop production in the tropics and increase the exports of desired agricultural goods, the Europeans who dominated the world at the turn of the twentieth century also had to invest massive amounts of capital, develop and transfer suitable technologies, and reorganize the tropical economies.[1]

In this they were successful. As economic historians have noted, global trade grew as rapidly as world industrial production until 1914, and much of this growth was in the trade between the tropics and the temperate zone.[2] Of particular importance for the growth of this trade were the introduction of compound-engine steamships and the opening of the Suez Canal, which together lowered freight rates by 50 percent between 1869 and 1910.[3] The cost of tropical goods, such as cotton, sugar, tea, and coffee, once rare luxuries, dropped until they became everyday necessities for the people of the industrial countries. As the Caribbean, south and southeast Asia, and later Africa turned increasingly to export agriculture, they in turn became important markets for other tropical countries' exports. Thus Burma, Siam, and Indochina became the rice baskets of Asia, feeding workers on the plantations of Java, Malaya, Ceylon, and Assam. Although the tropical economies did not industrialize or diversify, they nonetheless grew in step with those of the West.

The Golden Age of Botany

Most tropical exports were agricultural and exotic to Europe and North America. In the late eighteenth and nineteenth centuries, investiga-

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[1] On this point, see Daniel R. Headrick, *The Tentacles of Progress: Technology Transfer in the Age of Imperialism, 1850–1940* (New York, 1988).

[2] A. J. H. Latham, *The International Economy and the Under-Developed World 1865–1914* (London and Totowa, N.J., 1978); W. Arthur Lewis, ed., *Tropical Development, 1880–1913* (London, 1970).

[3] L. Isserlis, "Tramp Shipping Cargoes and Freights," *Journal of the Royal Statistical Society* 101 (1938): 53–134; see p. 122, table 8.

tions of the tropical flora by Louis Antoine de Bougainville, Joseph Banks, Alexander von Humboldt, and other travelers, and their classification by such botanists as Carl Linnaeus, Georges Louis Leclerc de Buffon, and Lamarck (Jean Baptiste de Monet) fueled a popular fascination with the plant world. Throughout this period, botany was admired and subsidized, the favorite science of governments and the upper classes.

Nineteenth-century Western botanists not only studied plants, they also transformed tropical agriculture. They had before them the example of numerous valuable plants transferred and commercialized in earlier centuries, such as cotton, tobacco, maize, manioc, and sugar cane. These early plant transfers had resulted from amateur initiatives. From the late eighteenth century on, however, plant transfers became official policy. At the urging of Joseph Banks, Britain's foremost botanist, the British government sent out Captain Bligh and the *Bounty* in 1787 to transfer breadfruit from Tahiti to Jamaica. Although Bligh's first voyage ended in a notorious mutiny, his second expedition in 1790 succeeded. Inspired by this success, Banks organized other expeditions to transfer tea, indigo, cotton, and mulberry bushes and silkworms from foreign countries to the British empire.[4]

Botanical Gardens

The full benefits of tropical agriculture could not, however, rest on sporadic individual or official initiatives. Further development required a scientific institution, the botanical garden. The Royal Botanic Gardens at Kew near London, originally a pleasure and apothecary garden, became a research center in the 1780s and a national institution in the 1840s. By the end of the nineteenth century, Kew held more than a million living plant species and corresponded with fifty-four other gardens, thirty-three of them in the British empire. The Jardin des Plantes in Paris played a similar role for France.[5]

Botanical gardens served many purposes. One was purely scientific:

[4] David Mackay, *In the Wake of Cook: Exploration, Science and Empire, 1780–1801* (New York, 1985), pp. 123–40, 168–88.

[5] On Kew Gardens, see Lucile H. Brockway, *Science and Colonial Expansion: The Role of the British Royal Botanic Gardens* (New York, 1979). On the Jardin des Plantes, see Camille Limoges, "The Development of the Muséum d'Histoire Naturelle of Paris, c. 1800–1914," in *The Organization of Science and Technology in France, 1808–1914*, ed. Robert Fox and George Weisz (Paris and London, 1980), pp. 211-40; and A. Davy de Virville, ed., *Histoire de la botanique en France* (Paris, 1954).

collecting and classifying the myriad plants found in the world, most of them in the tropics. Banks, the first director of Kew, had made his reputation by collecting plants during his Pacific voyages with Captain James Cook. Sir Joseph Hooker, director from 1865 to 1885, became the foremost British botanist of his time because of his collection of south Asian plants and his authoritative, seven-volume *Flora of British India*. The famous French botanists of the time, Buffon, Lamarck, and Jussieu, described and classified the flood of plants that filled greenhouses and herbaria.

Botanical gardens were intimately connected to the colonial empires of the period and their trade. The late eighteenth and early nineteenth centuries saw the founding of many botanical gardens in tropical colonies: St. Vincent and St. Thomas in 1764, Calcutta in 1768, Bourbon Island (now Réunion) in 1769, Jamaica in 1793, Perideniya in Ceylon (now Sri Lanka) in 1810, and Buitenzorg in Java in 1817. Then, after a lull in colonial expansion, many more were founded in the new territories conquered during the colonial scramble of the late nineteenth century.

Kew Gardens, the Jardin des Plantes, and other European botanical gardens regularly corresponded, traded seeds and plant material, and exchanged scientific personnel with one another and with their daughter establishments in the tropics. They also communicated across imperial borders, exchanging plants, information, and visiting scientists in the cooperative spirit of science.

Plant Transfers

Botanical gardens were very effective in transferring valuable plants, with major implications for world trade and tropical development. Among the thousands of such transfers, a few examples stand out. In the 1820s the Calcutta Botanical Garden helped transfer the tea bush from China to India and Ceylon.[6] More delicate plants had to await the invention of the terrarium in 1829 before they could survive long voyages across the oceans on sailing ships. Soon after, Dutch and British gardens sent teams of botanists around the world, especially to South America, in search of economically useful plants. In the 1850s and 1860s, Dutch and British agents spirited seeds of the wild cinchona tree, the source of quinine, from the Andes and transferred the

[6] Kalipada Biswas, ed., *Calcutta Royal Botanic Garden, 150th Anniversary Volume* (Alipore, 1942).

resulting seedlings to Java and India.[7] In the 1870s a British planter succeeded in smuggling seeds of the rubber tree *Hevea brasiliensis* from the Amazon to Kew Garden, and from there the seedlings were shipped to Ceylon, Singapore, and Malaya. These cloak-and-dagger operations formed the basis for two of the most important tropical crops.[8] In a less dramatic fashion, botanical gardens were also instrumental in the diffusion of coffee, sugar, cinnamon, sisal, tobacco, and many other plants.

By the late nineteenth century, botanists had transferred almost every commercially interesting plant, whether wild or cultivated, to almost every place on earth where they could profitably be grown. This involved primarily a massive transfer from South America to south and southeast Asia and the East Indies where conditions were favorable for labor-intensive estate-agriculture.

Experiment Stations

By the end of the nineteenth century, the emphasis in economic botany had turned from collecting and transferring plants to improving their potential through scientific research. Here the botanical garden of Buitenzorg in Java led the way. By the turn of the century, Buitenzorg was the foremost garden in the tropics, with 15 European and 300 Javanese employees and a budget two-thirds that of Kew. Ideally located for tropical gardening, it established an experiment station for the improvement of selected crops. Unlike the botanical garden, which collected thousands of species, the experiment station concentrated on a small number of crops—jute, peanuts, tobacco, rice, coffee, and soybeans—and studied them from the point of view of soil

[7] On the cinchona transfer, see Clements Robert Markham, *Travels in Peru and India while Superintending the Collection of Chinchona Plants and Seeds in South America, and their Introduction into India* (London, 1862); Donovan Williams, "Clements Markham and the Introduction of the Cinchona Tree into British India," *Geographical Journal* 128 (1962): 431–42; Gabriele Gramiccia, *Life of Charles Ledger (1818–1905): Alpacas and Quinine* (Basingstoke, 1988), pp. 16–19, 123–27; K. W. van Gorkum, "The Introduction of Cinchona into Java," in *Science and Scientists in the Netherlands' Indies*, ed. Pieter Honig and Frans Verdoorn (New York, 1945), pp. 182–90; and Brockway, *Science and Colonial Expansion*, pp. 104–33.

[8] On the *Hevea* transfer, see J. H. Drabble, *Rubber in Malaya, 1876–1922: The Genesis of an Industry* (Kuala Lumpur, 1973), pp. 1–5; Colin Barlow, *The Natural Rubber Industry: Its Development, Technology, and Economy in Malaysia* (Kuala Lumpur, 1978), pp. 18–20; and Warren Dean, *Brazil and the Struggle for Rubber: A Study in Environmental History* (Cambridge and New York, 1987), chap. 2. For a summary of these issues, see Headrick, *Tentacles of Progress*, pp. 209–58.

chemistry, mycology, entomology, genetics, and agronomy.[9] Its example was followed by agricultural research stations in Barbados in 1898, in India in 1903, and many others.[10]

The commerce-minded colonial governments of south and southeast Asia found such experiment stations useful, and the associations of agricultural exporters contributed as well. Beginning at the turn of the twentieth century and increasingly after World War I, planters' associations founded one-crop experiment stations and communicated the results to their members. Among the best known were the Imperial Sugarcane Breeding Institute in India, the East Java Experiment Station for sugar, the Union of Tobacco Planters' experiment station in Sumatra, the General Association of Rubber Planters of East Sumatra, and the Rubber Research Institute of Malaya.[11] Although the associations tried to keep the results of their research out of the hands of indigenous smallholders and the colonies of foreign powers, they were no more successful than the South American republics had been half a century earlier. Astonishing improvements in yields and methods spread rapidly; the rubber boom in French Indochina, for example, was almost entirely based on clones from Malaya and Sumatra.

Botanical Substitutes

Despite massive injections of scientific talent, capital, and labor, tropical colonies could not always keep up with the demand for their products, in quantity, price, or location. Inspired by the example of beet sugar, which had largely replaced cane sugar on the European continent during the nineteenth century, botanists sought close substitutes for the desired supplies, especially in the case of products that had strategic as well as commercial value.

[9] Melchior Treub, "Kurze Geschichte des botanischen Gartens zu Buitenzorg," in *Der botanische Garten "'s Lands Plantentuin" zu Buitenzorg auf Java. Festschrift zur Feier seines 75 Jährigen Bestehens* (1817–1892) (Leipzig, 1893), pp. 23–78; Treub, "Un jardin botanique tropical," *Revue des deux mondes* (January 1890): 162–83; and F. A. F. C. Went and F. W. Went, "A Short History of General Botany in the Netherlands Indies," in *Science and Scientists*, ed. Honig and Verdoorn, pp. 392–95.

[10] On agricultural extension in the British empire, see Geoffrey B. Masefield, *A Short History of Agriculture in the British Colonies* (New York, 1950); and Masefield, *A History of the Colonial Agricultural Service* (Oxford, 1972).

[11] See, for example, Frans Verdoorn and J. G. Verdoorn, "Scientific Institutions, Societies, and Research Workers in the Netherlands Indies," in *Science and Scientists*, ed. Honig and Verdoorn, pp. 425–29; and C. J. J. van Hall, "On Agricultural Research and Extension Work in Netherlands' Indies," in *Science in the Netherlands East Indies*, ed. L. M. R. Rutten (Amsterdam, 1929), pp. 268–73.

Countries that lacked *Hevea* rubber plantations experimented with alternative rubber-producing plants: *Landolphia* vines in French Equatorial Africa, *Manihot glazovii* in Central America, the guayule shrub (*Parthenium argentatum*) of Mexico and the United States, even a Russian dandelion (*Taraxacum koksagyz*).[12]

Gutta-percha, an important electrical insulator, is a case in point. Unlike the rubber tree, the *Palaquium* tree grew very slowly and had to be felled to extract its latex, the source of gutta-percha. Until 1900 the entire supply came from a dwindling number of wild trees scattered in the forests of Malaya, Sumatra, and Borneo, and was controlled by a few British companies. French, Dutch, and German botanists combed the forests looking for seeds. They also experimented with *Hevea* rubber and the sap of the *Balata*, the chewing-gum tree. Although nothing was quite as good as gutta-percha in insulating submarine telegraph cables, in the 1920s chemists concocted some close alternatives out of *Hevea* rubber, *Balata* gum, gutta-percha, and petroleum wax.[13]

Botany produced subsciences like plant genetics and agricultural mycology largely in response to the demands of Western commerce and the policies of the colonial powers. Although indigenous peoples were not consulted, the application of science to the tropics drastically changed the orientation of their agriculture, from local subsistence to the distant markets of the industrial world. Because the transformation was based on labor-intensive methods rather than labor-saving technologies, living standards remained steady while population grew.[14]

The Chemistry of Synthetics

The growth of tropical export agriculture slowed after 1914. At that point, world trade and industrial production, which had long increased at similar rates, suddenly diverged. While world industrial production continued to grow during the age of world wars, international trade stagnated or shrank (see table 1). Because the tropics played a large part in world trade but a very small one in industrial production, the

[12] Peter William Allan, *Natural Rubber and the Synthetics* (New York, 1972), pp. 33–34; Vernon Herbert and Atilio Bisio, *Synthetic Rubber: A Project That Had to Succeed* (Westport, Conn., 1985), p. 3.

[13] Daniel R. Headrick, "Gutta-Percha: A Case of Resource Depletion and International Rivalry," *IEEE Technology and Society Magazine* 6 (December 1987): 12–16.

[14] This is the theme of Clifford Geertz, *Agricultural Involution: The Process of Ecological Change in Indonesia* (Berkeley and Los Angeles, 1963), chaps. 4 and 5. See also Nathan Keyfitz, *Population Change and Social Policy* (Cambridge, Mass., 1982), pp. 56–58.

Table 1. World Trade and Industrial Production, 1820–1948 (average percentage growth per year)

Period	Trade	Industry
1820–40	2.81	2.9
1840–60	4.84	3.5
1860–70	5.53	2.9
1870–1900	3.24	3.7
1900–13	3.75	4.2
1913–29	0.72	2.7
1929–38	–1.15	2.0
1938–48	0	4.1

Source: W. W. Rostow, *The World Economy: History and Prospect* (Austin, 1978), p. 67.

age of wars and depression affected them more deeply than is usually admitted.

The gap between the industrial and the underdeveloped countries has widened since the turn of the twentieth century.[15] According to Angus Maddison, the per-capita gross domestic product (GDP) of the wealthy free-market countries grew by an average of 2.1% per year from 1900 to 1987, while that of Latin America grew by 1.7% per year and that of Asia (excluding Japan) by 1.3% per year. Some countries did much worse: Indonesia, 1%; the Philippines, 0.9%; India, 0.6%; and Bangladesh, producer of jute and indigo, 0.1%.[16] How can we explain the growth of industrial economies without a corresponding increase in the production of tropical raw materials? The answer is that the industrial countries found substitutes for their tropical imports, thanks to chemistry.

Synthetic Dyestuffs

By the middle of the nineteenth century, chemists had laid the foundations of quantitative and inorganic chemistry and had begun to investigate the far more complex world of organic chemicals. Among the leaders in this field were Justus von Liebig, professor of chemistry at Giessen, and his disciple August Wilhelm von Hoffman, who taught

[15] Paul Bairoch, "The Main Trends in National Economic Disparities since the Industrial Revolution," in *Disparities in Economic Development since the Industrial Revolution*, ed. Paul Bairoch and Maurice Lévy-Leboyer (Houndmills, England, 1981), pp. 1–17.

[16] Angus Maddison, *The World Economy in the Twentieth Century* (Paris, 1989), p. 15.

at the Royal College of Chemistry in London. In the 1850s all the world's quinine was extracted from the bark of cinchona trees growing wild in the Andes, an erratic and diminishing source of supply. The same motive that impelled Dutch and British botanists to steal cinchona seeds and transfer the plants to India and Java inspired Hoffman and his students to try to synthesize quinine from aniline, a coal tar derivative. It was a goal that continued to elude scientists until World War II.

While experimenting with aniline, one of Hoffman's students, William Perkin, stumbled upon mauve, a synthetic dyestuff that was superior to the natural dyes then in use. Perkin founded a company to exploit his discovery and soon thereafter introduced synthetic magenta, and then violet, blue, and black dyes.[17]

Although pioneered by an Englishman, the dye industry flourished in Germany, where it became the focus of cooperative research in university and industrial laboratories. In 1868 two German industrial chemists, Carl Graebe and Carl Libermann, synthesized the red dye alizarin. Then in 1890 Karl Heumann patented the blue dye indigo. By the turn of the century, chemists had synthesized many other popular dyes and found ways to produce them at lower costs than their natural competitors.[18]

Characteristically, the big German chemical companies were named for their aniline dyes: Badische Anilin und Sodafabrik, or BASF; Aktiengesellschaft für Anilin Fabrikation, or AGFA; Farbwerke (dye works) Hoechst; and Farbenfabriken (dye factories) Bayer. In the 1920s these four companies and three smaller ones merged to form Interessengemeinschaft Farbenindustrie (community of interest for the dye industry), I. G. Farben for short.[19]

Polymers, Plastics, and Fibers

These early successes, though significant, pale in comparison to the synthesis of plastics, fibers, and rubber. These synthetics are chemically similar, consisting for the most part of long organic molecules

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[17] Anthony S. Travis, "Perkin's Mauve: Ancestor of the Organic Chemical Industry," *Technology and Culture* 31 (1990): 51–80; Travis, *The Rainbow Makers: The Origins of the Synthetic Dyestuff Industry in Western Europe* (Bethlehem, Pa., 1993), pp. 35–44.

[18] John J. Beer, *The Emergence of the German Dye Industry* (Urbana, Ill., 1959); and Travis, *Rainbow Makers*, pp. 164–226.

[19] Peter H. Spitz, *Petrochemicals: The Rise of an Industry* (New York, 1988), pp. 18–33; Vivien Walsh, "Invention and Innovation in the Chemical Industry: Demand-Pull or Discovery-Push?" *Research Policy* 13 (1984): 211–34.

called polymers. From the point of view of producers and consumers, however, it is logical to distinguish them by their end uses.

Since the late eighteenth century, Europeans had known of several natural plastics, that is to say, materials that soften when heated and retain their shape after they cool. The first was shellac, made from the same Indian insect *Coccus lacca* that produced the red dye lac; it was used to make buttons and other small molded articles, among them the first phonograph records. Another was gutta-percha, which began to be used in the 1850s to make molded household articles and to insulate submarine telegraph cables.

During the second half of the nineteenth century, inventors came up with several semi-synthetic plastics, natural products chemically transformed into plastics. The most important were ebonite, a composite of natural rubber and sulfur invented by Nelson Goodyear in 1851, and celluloid, created in 1869 by John Wesley Hyatt as a substitute for ivory in billiard balls.[20]

The first true synthetic plastic, however, was bakelite, a composite of phenol and formaldehyde created in 1910 by Leo Baekeland. A dark substance with good dielectric properties, it was widely used to make radio cabinets, phonograph records, fountain pens, and other modern items. It was soon displaced by urea-formaldehyde, a substance with the same qualities that could by dyed a range of bright colors. Both were thermosetting, that is, once molded they became hard and would not lose their shape when reheated.

Progress in this field was slow, the result of trial and error and serendipitous discoveries rather than science. During the 1920s, however, Hermann Staudinger, a chemist at BASF, explained the polymerization, or linking, of monomers, the basic molecular building blocks of complex hydrocarbons. When these monomers formed long chains, loosely tangled like a bowl of spaghetti, they became thermoplastics that retained the ability to soften when heated. When the chains became linked to one another like knitted yarn, they formed thermoset plastics that would not melt. Wallace Carothers, a chemist working at Du Pont, continued Staudinger's investigations into polymers, opening the way to creating new materials with specific characteristics, such as neoprene rubber and nylon.[21]

The 1930s and 1940s were a particularly fertile period for polymer

[20] Robert Friedel, *Pioneer Plastic: The Making and Selling of Celluloid* (Madison, Wis., 1983).

[21] On Wallace Carothers, see David A. Hounshell and John K. Smith, Jr., *Science and Corporate Strategy: Du Pont R&D, 1902–1980* (New York, 1988), pp. 229–46.

science, as chemists synthesized one new plastic after another. Polyvinyl chloride (PVC), first manufactured by Du Pont and I. G. Farben in 1933, was made into floor tiles, phonograph records, pipes, dentures, furniture, and insulation. Very similar was polystyrene, manufactured by Dow Chemical and I. G. Farben from 1937 on; it was used as a foam, adhesive, and emulsion, as well as a hard plastic. By 1945 the United States was producing 60,000 tons of PVC and 7.5 million tons of polystyrene each year.

The most ubiquitous plastic of all is polyethylene. It was discovered by accident by Francis Freeth and his colleagues at Imperial Chemical Industries, a British firm that had until then shown little interest in plastics. While experimenting, against company rules, with high-pressure equipment, they left a mixture of ethylene and benzaldehyde overnight at a pressure of 2,000 atmospheres and a temperature of 170°C. The next day they found that a waxy residue had replaced the gases. The experiment lay forgotten for three years until it was unearthed in late 1935. The waxy substance, polyethylene, had excellent dielectric properties, especially for high-frequency equipment, and was used during World War II to insulate cables and wires in radar sets. After the war, new manufacturing techniques and an abundance of petroleum feedstocks made it cheap enough for throw-away packaging material. By 1978 the world's production of plastics—most of it polyethylene—had surpassed that of iron and steel.[22]

Synthetic fibers are basically also polymers, drawn out into long thin filaments. Their evolution therefore parallels that of other plastics. The first such fiber was rayon, a form of celluloid invented in the 1880s and sold as "artificial silk." A better semi-synthetic, also based on cellulose, was acetate, discovered in 1913 and marketed in the 1920s.

The first real competitor to silk, however, was polyamide fiber, first synthesized by Carothers of Du Pont in 1935 and marketed as nylon in the United States in 1936 and as Perlon in Germany in 1939.[23] It was used to make parachutes during the war and later stockings and much else. It was followed after the war by acrylics (Orlon, Dynel, Dralon) and polyester (Dacron, Terylene).[24]

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[22] Spitz, *Petrochemicals*, pp. 49, 227–68; Herman F. Mark, "The Development of Plastics," *American Scientist* 72 (1984): 156–62; D. W. F. Hardie and J. Davidson Platt, *A History of the Modern British Chemical Industry* (Oxford, 1966); and William J. Reader, *Imperial Chemical Industries: A History*, 2 vols. (London, 1975), 2:338–58.

[23] Hounshell and Smith, *Science and Corporate Strategy*, pp. 224–74.

[24] Spitz, *Petrochemicals*, pp. 51, 237, 272–87.

Synthetic Rubber

The search for synthetic rubber was the most intensive of all such endeavors, and the one most fraught with political and economic consequences, for only rubber was suitable for making automobile tires. After 1910 almost all natural rubber came from southeast Asia and the Dutch East Indies, leaving the automobile industry at the mercy of erratic supplies, fluctuating prices, and cartels.

American industries, then dominant in the manufacture of automobiles and their tires, made several attempts to grow *Hevea* trees elsewhere. In 1926 the Firestone Tire and Rubber Company opened *Hevea* plantations in Liberia, which did well, though on a much smaller scale than the estates of southeast Asia. A year later Henry Ford decided that *Hevea* ought to grow well in its native habitat, the Amazon; the Ford Motor Company obtained a million hectares from the Brazilian government, planted seedlings imported from Singapore, and discovered, after years of efforts, that the Amazon was also the home of a leaf blight that devastated *Hevea* trees.[25]

The southeast Asian output of natural rubber usually kept up with the demand. The search for a synthetic substitute depended on corporate funding, which fluctuated with the price of natural rubber. During World War I the Entente powers showed little interest in synthetic rubber, because natural rubber supplies were abundant. Germany, however, was cut off from the sources of natural rubber; in response, Bayer and BASF managed to convert coal and limestone into methyl rubber, a very costly substance so hard it was only used for submarine batteries.[26]

Research picked up after the war, especially in 1925 when speculation briefly drove up the price of natural rubber from 12 cents to $1.12 a pound. As it had in the case of plastics, research in the theory of polymerization led to major breakthroughs in both Germany and the United States.

German firms worked sporadically on synthetic rubber research during the 1920s. In the early 1930s chemists at I. G. Farben created Buna-S, a substance with the properties required for tires, but their research was slowed by the Depression. Then in 1934 Adolf Hitler announced at the seventh Nazi Party congress in Nuremberg that "the

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[25] Allan, *Natural Rubber*, p. 39; Dean, *Brazil*, pp. 71–84. See also Charles Morrow Wilson, *Trees and Test Tubes: The Story of Rubber* (New York, 1943), an optimistic account written when there was still hope that the Ford plantation might succeed.

[26] Allan, *Natural Rubber*, p. 47; Herbert and Bisio, *Synthetic Rubber*, p. 27.

problem of producing synthetic rubber can now be regarded as definitely solved. The erection of the first factory in Germany for this purpose will be started at once." Moved by these inspiring words, I. G. Farben built a plant to produce Buna-S. It was soon followed by the synthesis of Buna-N, a rubber that resisted chemicals and oils. Although they cost more than natural rubber, the synthetics allowed Germany to equip its armed forces with the vehicles without which it could not have fought another war.[27]

Synthetic rubber research in the United States was closely tied to the German efforts, thanks to patent-sharing agreements between I. G. Farben and several American firms. The Depression and the resulting glut of natural rubber diverted research from tire rubber substitutes to specialty rubbers. In 1931 Carothers at Du Pont synthesized the heat- and oil-resistant neoprene, used for hoses, electrical insulation, and other industrial applications.[28] Then in 1937 William Sparks and Robert Thomas at Standard Oil of New Jersey created butyl, the ideal material for inner tubes. Although these were important for their particular purposes, they accounted for less than 1% of U.S. rubber consumption as late as 1941.

Even after two years of war in Europe, no one in the United States expected the Japanese to conquer southeast Asia and cut off natural rubber supplies. By early 1942 stockpiles were dangerously low. Imports from Latin America, Africa, and Ceylon increased somewhat, but they provided hardly one-third of normal U.S. consumption. Under government control and with heavy subsidies, the chemical companies quickly built enough manufacturing facilities to make up for the shortfall in natural rubber. By August 1942 fourteen rubber plants had been built or were under construction, of which eleven produced a total of 705,000 tons of Buna-S a year, while one made neoprene and two produced butyl. By 1944 the United States was meeting all its own rubber needs and those of its allies as well (see table 2).[29]

The manufacture of synthetic rubber during the war was clearly an emergency measure, heavily subsidized and not expected to compete

[27] Peter Hayes, *Industry and Ideology: IG Farben in the Nazi Era* (Cambridge, 1987); see also Herbert and Bisio, *Synthetic Rubber*, pp. 31–33; Allan, *Natural Rubber*, p. 48; and Spitz, *Petrochemicals*, p. 3.

[28] Hounshell and Smith, *Science and Corporate Strategy*, pp. 233–49.

[29] Robert A. Solo, *Across the High Technology Threshold: The Case of Synthetic Rubber* (Norwood, Pa., 1980); Peter J. T. Morris, *The American Synthetic Rubber Research Program* (Philadelphia, 1989), pp. 7–14; Herbert and Bisio, *Synthetic Rubber*, p. 66. On the politics of wartime rubber, see William N. Tuttle, Jr., "The Birth of an Industry: The Synthetic Rubber 'Mess' in World War II," *Technology and Culture* 22 (1981): 35–67.

Table 2. U.S. Rubber Supplies in World War II (amounts in tons and percentages)

Year	Imports of Natural Rubber	Synthetic Rubber	Reclaimed Rubber	Total Supplies
1941	1,029,007 (78%)	8,383 (0.6%)	274,202 (21%)	1,311,592
1942	282,653 (48%)	22,434 (4%)	286,007 (48%)	591,094
1943	55,329 (9%)	231,722 (39%)	310,429 (52%)	597,480
1944	107,834 (9%)	773,673 (68%)	260,514 (23%)	1,142,021
1945	137,237 (11%)	830,780 (69%)	238,772 (20%)	1,206,789

Source: Vernon Herbert and Atilio Bisio, *Synthetic Rubber: A Project That Had to Succeed* (Westport, Conn., 1985), p. 127.

with natural rubber in peacetime. Indeed, as soon as the war ended, southeast Asian rubber growers once again tapped the trees left unattended during the war. Natural rubber production bounced back up to its prewar levels and by 1950 had recaptured four-fifths of the world market.[30]

Synthetic rubber soon recovered from its postwar slump. After the U.S. government privatized the industry in 1953, production expanded rapidly, catching up with natural rubber by 1960. Thanks to technological advances, synthetic rubber replaced its natural rival as the material of choice for automobile tires, which represented two-thirds of the rubber market. Synthetic rubber manufacturing has even spread to countries that once produced natural rubber, such as Brazil, Mexico, and India.[31]

Consequences of Chemical Substitution

Motives of Chemical Substitution

Clearly, synthetic materials are much more than substitutes for natural products. No matter how inexpensive, natural products could not replace the plethora of synthetic dyes, plastics, fibers, rubbers, and other chemical substances on which industrial civilization depends. Synthetics are essentially new materials, the products of important industries and major contributors to the standard of living and the culture of

[30] Allan, *Natural Rubber*, p. 20.

[31] Allan, *Natural Rubber*, pp. 49–53; Herbert and Bisio, *Synthetic Rubber*, pp. 139, 209; Barlow, *Natural Rubber Industry*, chap. 10.

the inhabitants of the industrialized countries. To quote the motto of the Du Pont Corporation, they bring "better living through chemistry."

The impact of synthetics, however, has varied enormously among different parts of the world. As often happens with new technologies, their consequences are only tenuously related to the aims of their creators. Let us first consider these aims.

In an analysis of invention and innovation in the chemical industry, Vivien Walsh has concluded that polymer plastics resulted more from "science-push" than "demand-pull," though "anticipated demand" did play a role.[32] Science-push refers to the activities of scientists who perform experiments for their own sake, often with unanticipated results. The most striking examples are Perkin's discovery of aniline dye while seeking a substitute for quinine and the serendipitous discovery of polyethylene by Freeth, experimenting after hours against company rules.

Anticipated demand refers to the decisions of corporate executives who must invest capital in salaries, equipment, and supplies in their laboratories in the hope of obtaining a product or process that will prove profitable. Such decisions usually promote secondary inventions in the wake of a major discovery. Thus, the German dyestuff industry was established to extend and improve on Perkin's discovery, and the development of polymer plastics by Du Pont and BASF was based on the example of celluloid and bakelite and on the researches of Staudinger and Carothers.

A special form of anticipated demand is the preparation for war. The connection between war and research became clear in World War I. Before the battle of the Marne in September 1914, the German High Command had not considered the possibility that its army might need a source of explosives other than Chilean nitrates. It was rescued from a quick defeat by the Haber-Bosch nitrogen fixation process, invented for other reasons. After that experience, the German military became obsessed with the need to use local raw materials, especially coal, to replace imports from overseas, such as petroleum and rubber. The other great powers also became aware that their dependence on the tropics made them vulnerable to invasions and submarine campaigns. One of the significant consequences of the two world wars was to provoke a search for synthetics made from temperate-zone materials to replace natural products from the tropics.[33]

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[32] Walsh, "Invention and Innovation," pp. 224–25.

[33] Jeffrey Allan Johnson, *The Kaiser's Chemists: Science and Modernization in Imperial Germany* (Chapel Hill, N.C., 1990), pp. 184–89; Ludwig F. Haber, *The Chemical Indus-*

Consequences for the Tropics

For the tropics, the development of synthetics has been at best a mixed blessing and sometimes a disaster. Underdevelopment is caused by many factors, one of which is the loss of markets. Whether originally developed for war or in the competition between powerful companies, synthetics have reduced the industrial world's dependence on the tropics. As a result, the demand for tropical products has kept up neither with the wealthy countries' industrial production nor with the tropical countries' demand for industrial products. In some instances, their markets have stagnated; in others, they have shrunk or vanished.

The enormous growth in demand for fibers has mainly benefitted the synthetics. While world production of cotton fluctuated between 60 and 90 billion tons per year between 1910 and 1960, synthetic fibers rose from near zero to 100 billion tons, half for semi-synthetics and half for pure synthetics.[34] Synthetics, especially nylon and polyester, have also eaten into the markets for natural industrial packaging materials, such as jute, hemp, and sisal.[35]

Natural dyes fared much worse. Madder root, of which the British textile industry imported 15,000 tons a year between 1850 and 1870, had been entirely replaced by alizarin by 1900, to the detriment of farmers in Turkey and southern France. With the introduction of synthetic indigo, the amount of land in India planted in natural indigo dropped from 1.7 million acres in 1897 to 150,000 acres in 1914, while exports fell from 19,000 tons in 1895–96 to 1,100 tons in 1913–14.[36] The market for camwood, a red dye that once constituted one of Liberia's major exports, simply vanished.[37] Other natural dyes, such as the carmine dye from the cochineal of Mexico and the Canary Islands, black from the West Indian logwood tree, red from Indian lac, crimson and purple from brazilwood, and green from the Chinese lokao tree, practically disappeared from the world market. So have the natural plastics, shellac, and gutta-percha.

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try, 1900–1930 (Oxford, 1971), pp. 90–95; Frank Greenaway et al., "Heavy Inorganic Chemicals," in *A History of Technology*, vol. 6: *The Twentieth Century, c. 1900 to c. 1950*, part 1, ed. Trevor I. Williams (Oxford, 1978), pp. 514–32; and Spitz, *Petrochemicals*, pp. 25–29.

[34] Walsh, "Invention and Innovation," p. 221; Spitz, *Petrochemicals*, pp. 271, 292.

[35] On the disappearance of the market for sisal and its impact on a tropical agricultural region, see Anthony DePalma, "In a World of Plastics, Can Yucatan Find a Place?" *New York Times*, 26 August 1993.

[36] Travis, *Rainbow Makers*, p. 226.

[37] J. B. Webster and A. A. Boahen, *History of West Africa: The Revolutionary Years, 1815–Independence* (New York, 1967), pp. 150–52.

The Return of Natural Rubber

There is one remarkable exception to this trend. While the markets for many tropical products have dried up, one product—natural rubber—has held its own against the largest and most powerful of all the synthetics industries. Its success helps explain the weakness of other tropical products.

Most of the growth in natural rubber production since 1960 came not from increases in labor or land inputs, but from technological innovation. The Malaysian government imposed an export tax that supported the laboratories of the Rubber Research Institute of Malaysia and the Natural Rubber Producers' Research Association. It also established effective agricultural extension services and cooperative processing for smallholders, and marketing and technical advisory services abroad.[38] According to the historian of rubber Peter Allan, "natural rubber's ability to survive and grow in a background of aggressive competition from the synthetics stems in part from its innate technical qualities, in part from the prodigious human effort deployed into its production, marketing and usage development."[39] By 1973 the Rubber Research Institute of Malaysia had 167 senior research officers, 300 extension agents, and more than 1,000 junior staff; it was, in Colin Barlow's words, "the largest research organization of its kind in the tropics."[40] After World War II most *Hevea* trees in Malaya were more than thirty years old and yielded only 400–500 kg latex per hectare. Between 1960 and 1973 low-yielding trees were replaced with new clones yielding more than 1,000 kg per hectare. With new fertilizers, tapping procedures, and chemical stimulants, even older trees could be made to double their yields. More recently, yields have reached 1,800–3,000 kg per hectare.[41] As a result of these efforts, natural rubber regained much of the ground it had lost to synthetics in the 1950s and 1960s, and by 1988 it had recaptured one-third of the world rubber market.[42]

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[38] Allan, *Natural Rubber*, pp. 43–77, 181–82; Barlow, *Natural Rubber Industry*, pp. 74, 88–91, 115–16, 148–49, 161–67.

[39] Allan, *Natural Rubber*, p. 218.

[40] Barlow, *Natural Rubber Industry*, pp. 88–91.

[41] P. P. Courtenay, "Some Trends in the Peninsular Malaysian Plantation Sector, 1963–1973," in *Issues in Malaysian Development*, ed. James C. Jackson and Martin Rudner (Singapore, 1979), pp. 148–53; and Barlow, *Natural Rubber Industry*, pp. 81–86, 121, 444–45. On the technical aspects of rubber cultivation, see M. R. Sethuraj and N. M. Mathew, eds., *Natural Rubber: Biology, Cultivation, and Technology* (Amsterdam, 1992).

[42] David Creffield, *Malaysia* (London, 1990), p. 132; see also Ahmad Farouk bin Haji S. M. Ishak, "Changes and Trends in the Natural Rubber Industry: An Overview," in *Developments in the Plastics and Rubber Products Industries*, ed. J. C. Rajarao (Kuala Lumpur, 1987), pp. 57–89; and Abdul Aziz bin S. A. Kadir, *Toward Greater Viability of the Natural Rubber Industry* (Kuala Lumpur, 1991), pp. 43–76.

Table 3. Personnel and Expenditures for Research and Development, Estimates for 1980, 1985, and 1990

	Scientists and Engineers in R&D per Million Inhabitants			Expenditures for R&D as Percentage of GNP		
Region	1980	1985	1990	1980	1985	1990
World	894	920	1,000	1.85	2.22	2.55
North America	2,734	3,024	3,359	2.23	2.66	3.16
Europe	1,859	1,927	2,206	1.81	2.02	2.21
Oceania	1,774	1,414	1,610	1.25	1.20	1.38
Asia (excluding Arab nations)	304	336	396	1.41	1.80	2.08
Arab nations	330	336	363	.97	.94	.76
Latin America & Caribbean	242	312	364	.44	.43	.40
Africa (excluding Arab nations)	84	72	74	.30	.28	.29

Source: UNESCO, *Statistical Yearbook 1991* (Paris, 1991), table 5.2.

The case of natural rubber in Malaysia gives us a clue to understanding the economic impact of technological change on different parts of the world. The decisive factor is not chemistry versus botany, or the temperate zone versus the tropics. Rather, it is research.

The Global Distribution of Research

The figures are revealing. In 1980 the developing countries, with more than three-quarters of the world's population, had only 10.6% of the world's scientists and engineers and incurred only 6% of the world's expenditures for research and development (R&D).[43] Interest in R&D varies widely throughout the world (see table 3). In the developed countries of North America, Europe, and Oceania, a larger proportion of the population is engaged in R&D than in Asia, Latin America, or the Arab nations, while the latter regions, in turn, are well ahead of sub-Saharan Africa. In proportion of their GDPs devoted to R&D, the countries of Asia (excluding the Arab nations) have joined the developed countries.

If we look more closely at research and development in selected countries (generally the larger or more populated ones in each area), a more diverse pattern emerges, with the most industrialized or prosperous countries having the highest proportion of their population engaged in R&D, two fast developing countries—Brazil and Malaysia—

[43] Jacques Gaillard, *Scientists in the Third World* (Lexington, Ky., 1991), p. xiv.

Table 4. Scientists and Engineers Engaged in Research and Experimental Development, Selected Countries and Years (1980s)

Country	Year	No. Scientists and Engineers	Scientists & Engineers per Million Inhabitants
Japan	1989	636,817	5,263
United States	1988	949,200	3,988
Netherlands	1988	37,520	2,680
Canada	1988	61,130	2,445
Australia	1988	38,568	2,411
France	1988	115,163	2,094
Italy	1988	74,833	1,313
Brazil	1985	52,863	389
Malaysia	1988	5,537	346
Turkey	1985	11,276	246
Peru	1981	4,858	243
Mexico	1984	16,679	214
Indonesia	1988	32,038	194
India	1988	119,027	158
Philippines	1984	4,830	88
Nigeria	1987	1,338	14

Source: UNESCO, *Statistical Yearbook 1991* (Paris, 1991), table 5.4.

in the middle, and the rest of the developing countries listed roughly in the order of their economic growth (see table 4).

Finally, if we look at research in agriculture, the critical sector of all tropical economies, yet another pattern emerges (see table 5). The prosperous and industrial countries devote the most money and the highest proportion of their population to agricultural R&D, while countries in the tropics that are heavily dependent on agriculture devote little money and few people to that sector. A notable exception is Malaysia, which has not only rescued its rubber plantations from the competition of synthetic rubber, but has also increased its exports of palm oil sixteenfold and those of cocoa seventy-five-fold from 1970 to 1993.[44] Other tropical countries have invested far less than Malaysia in research and development and have, as a result, had slower economic growth.

Conclusion

In the nineteenth century, research in botany and agronomy by scientists from the industrial north transformed the tropics. Then, in the

[44] "Poor Relations," *Economist*, 16 April 1994, p. 76.

Table 5. Public Agricultural Research, 1981–85

Country	Expenditures per capita (in U.S. dollars)	Researchers per Million Inhabitants
Canada	16.85	109
Australia	14.76	286
Netherlands	13.55	116
Japan	8.44	122
Malaysia	6.93	51
United States	5.98	60
France	4.39	43
Italy	3.18	41
Turkey	2.15	32
Brazil	2.15	27
Mexico	1.65	14
Kenya	1.36	23
Peru	1.01	13
Algeria	.97	14
Indonesia	.86	8
Nigeria	.83	18
Bangladesh	.69	9
India	.60	11
Philippines	.52	36

Source: World Resources 1994–95: A Report by the World Resources Institute (New York and Oxford, 1994), table 18.5; population data from UNESCO, *Statistical Yearbook 1991 (Paris, 1991)*, table 1.1.

twentieth century, the industrial north invested heavily in chemical synthetics, thereby reducing the market for many tropical products. For some tropical countries, the shrinking of their markets and rapid population growth have resulted in economic stagnation and widespread poverty; others, meanwhile, have found in research a means of achieving a satisfactory rate of economic growth.

In the twenty-first century, under its new name of genetic engineering, botany may once again rival chemistry as a source of endless "miracles" and the engine of economic growth.[45] Whether that happens or not, one outcome is certain: in the future as in the past, research will be an engine of economic growth, and countries that invest in research will prosper at the expense of those that do not.

[45] Today, as in the nineteenth century, scientists from the advanced industrial countries scour the tropics for plants and even microbes that might be turned into profitable products; see Madhusree Mukerjee, "Little Winners," *Scientific American* (June 1994): 105–106.